PB86-101169

Products Identified at an Alternative Disinfection Pilot Plant

(U.S.) Environmental Protection Agency
Cincinnati, OH

Sep 85

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PB86-101169

EPA/600/D-85/203
September 1985

PRODUCTS IDENTIFIED AT AN ALTERNATIVE DISINFECTION PILOT PLANT

by

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CINCINNATI, OH 45268

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TECHNICAL REPORT DATA
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1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA/600/D-85/203		PB86 101169/AS

4. TITLE AND SUBTITLE	5. REPORT DATE
Products Identified at an Alternative Disinfection Pilot Plant	September 1985
	6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
B.W. Lykins, Jr.,[1] and W. Koffskey[2]	

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
1. USEPA, Cincinnati, OH 45268 2. Jefferson Parish Dept. Public Utilities Jefferson, LA 70181	11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Water Engineering Research Laboratory- Cincinnati, OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268	14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
For information, contact B.W. Lykins, Jr., 513-569-7460

16. ABSTRACT

Many drinking water utilities have recently changed or are considering changing their disinfection practice from chlorine to some alternative. Because changes are being made without evaluating the chemical effect, this study evaluated four parallel streams dosed with four disinfectants: chlorine, monochloramine, chlorine dioxide, and ozone. These streams along with a fifth parallel stream without disinfection (control) were passed through both sand and granular activated carbon.

Ozonation reduced the total organic carbon (TOC) by 0.3 mg/L and the total organic halide (TOX) concentration by 10 ug/L. The average TOC concentration for the other disinfectants was comparable to nondisinfection (3.3 mg/L). After 30 min contact time, the average instantaneous TOX concentration for chlorine dioxide disinfection increased by 60 ug/L; for chloramine, by 92 ug/L; and for chlorine, 238 ug/L from a nondisinfected concentration of 25 ug/L.

The volatile organics most affected by disinfection (chlorination) were the trihalomethanes. For the other volatile organics evaluated, no significant change in concentration was noted after disinfection. For most of the nonvolatiles evaluated, ozonation reduced the average concentration between 11% and 84%. Conversely, for some nonvolatile organics, chlorination increased the concentration between 43% and 100%.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	36
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

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PRODUCTS IDENTIFIED AT AN ALTERNATIVE DISINFECTION PILOT PLANT

by

Ben W. Lykins, Jr. and Wayne Koffskey

ABSTRACT. Many drinking water utilities have recently changed or they are seriously considering changing their disinfection practice from chlorine to some alternative. A majority of these utilities are changing their disinfectants without evaluating chemical impacts. Therefore, a research cooperative agreement was developed with Jefferson Parish, Louisiana to evaluate four parallel streams dosed with four different disinfectants (chlorine, monochloramine, chlorine dioxide, and ozone.) These streams along with a fifth parallel stream without disinfection (control) were passed through both sand and granular activated carbon.

Ozonation reduced the total organic carbon (TOC) and total organic halide (TOX) concentration by 0.3 mg/L and 10 ug/L, respectively. The average concentration of the TOC for the other disinfectants was comparable to non-disinfection (3.3 mg/L). The average instantaneous TOX concentration for chlorine dioxide, chloramine, and chlorine disinfection after 30 minutes contact time increased by 60, 92, and 238 ug/L, respectively, from a nondisinfected concentration of 25 ug/L.

The volatile organics most effected by disinfection (chlorination) were the trihalomethanes. No significant change in concentration was noted after disinfection for other volatile organics evaluated, such as 1,2dichlorethane, dichloromethane, trichloroethylene, 1,1,2-trichloroethane, and carbon tetrachloride. Ozonation produced an average concen-

tration reduction of 11-84% for most of the non-volatiles evaluated. Conversely, a concentration increase of 43-100% was noted after chlorination for some of the nonvolatile organics.

PRODUCTS IDENTIFIED AT AN ALTERNATIVE DISINFECTION PILOT PLANT

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Introduction

Many drinking water utilities have recently changed, or they are seriously considering changing, their disinfection practice from chlorine to some alternative. This type of treatment decision is primarily a result of regulations to control trihalomethanes[1]. A majority of these water utilities have changed to alternative disinfectants without evaluating possible chemical impacts.

Various river systems provide the water source for many of these drinking water utilities. One river is the Mississippi. In its 2400 mile course to the Gulf of Mexico, this river drains nearly two-thirds of the Continental United States. At the end of this river is Jefferson Parish, Louisiana where a research cooperative agreement was developed to evaluate four parallel streams dosed with four different disinfectants (chlorine, monochloramine, chlorine dioxide, and ozone). These streams along with a fifth parallel stream without disinfection (control) were evaluated for chemical constituents, microbiological changes, and health effects.

Research Objectives

A portion of the research effort at Jefferson Parish, Louisiana was developed to investigate the chemical and health effects of disinfec-

tants and disinfection by-products. The objectives for this one-year study were to (1) identify chemical and biological contaminants in filtered water prior to disinfection, (2) evaluate chemical by-product formation and biological effects after disinfection, (3) evaluate the effectiveness of granular activated carbon (GAC) for removing chemical contaminants present in the water or formed during disinfection as compared to sand filtration, (4) evaluate the effects of post adsorption disinfection with monochloramine and free chlorine on the pilot column effluents, and (5) collect samples for evaluating the health effects of the four disinfectants used in the pilot plant study. The activity for (5) is not reported in this paper.

Pilot Plant

Raw river water from the Mississippi River was pumped to the full-scale (Permutit III) plant where it was clarified with dillyldimethylammonium chloride and/or dimethylamine type cationic polymers[3]. After fluoridation, but before any disinfection, a portion of the clarified water was filtered through pressure sand filters and split into five process streams (Figure 1). Each disinfected process stream consisted of a contact chamber followed by parallel filtration through a sand column, a granular activated carbon (GAC) column, and a duplicate GAC column. The nondisinfected process stream was identical to the disinfected process streams except for elimination of the contact chamber.

Each disinfectant contact chamber was 12.75 in. outside diameter (O.D.) and constructed of stainless steel with stainless steel flanged or capped ends. The chlorine, chloramine, and chlorine dioxide contact

chambers were 10 ft. in height producing approximately thirty minutes of disinfectant contact time with a flow of 2 gallons/minute (GPM). The ozone contact chamber was 11 ft. in height with countercurrent operation consisting of water entering at the top of the contact chamber and ozone gas entering at the bottom. The water and ozone gas influent lines were oriented so that the influent water would be in contact with the ozone gas stream for approximately 30 minutes.

Each pilot column was 6 in. inside diameter (I.D) and 10 ft. in height. The pilot columns were charged with 6.8 ft. of either sand or GAC to obtain a 20 minute empty bed contact time with a flow of 0.5 GPM. A portion of the process streams was collected in bottles and redisinfected with chlorine or chloramine after passing through the pilot GAC columns.

Disinfectant Residuals

The average disinfectant contact time for the one year operational period was 31.8, 31.4, 32.1 and 31.7 minutes, respectively, for chlorine, monochloramine, chlorine dioxide, and ozone. From this contact time, an average residual of 1.0 mg/L chlorine, 2.1 mg/L monochloramine, 0.5 mg/L chlorine dioxide, and 0.5 mg/L ozone was maintained (Table 1). These concentrations are comparable to the residuals produced by many water utilities. After addition of the various disinfectants, the pH changed no more than 0.1 units from the median influent pH of 7.5.

All of the disinfectants except ozone had other associated disinfection products (Table 1). Chlorine, for instance, had an average monochloramine residual of 0.2 mg/L and an average dichloramine residual of 0.3 mg/L attributable to the presence of 0.1-0.2 mg/L of ammonia nitrogen.

Also, chlorite was present in the chlorine dioxide residual at a concentration of 0.6 mg/L as compared to 0.5 mg/L for the chlorine dioxide. Essentially all of the chlorite resulted from reduction of chlorine dioxide.

Ozone was generated from compressed dry air using an electrically powered ozone generator with a maximum output capacity of 0.25 lb/day. Chlorine dioxide was generated using sodium chlorite and sodium hypochlorite with sulfuric acid added to adjust the pH to 4. A 96 percent yield of chlorine dioxide was obtained. Chlorine gas was fed to both the chloramine and chlorine process streams. Ammonia was added to the chloramine process stream in the form of an ammonium hydroxide solution ahead of the chlorine eductor.

Disinfectant Effectiveness

After approximately thirty minutes of disinfectant contact time, ozone had the highest level of disinfection relative to standard plate count (SPC) followed by chlorine dioxide, chlorine, and chloramine. After sand filtration, chlorine dioxide, chlorine, and chloramine produced similar counts of about 50/ml. The geometric mean for the SPC increased from 8 counts/ml to 4594 counts/ml for the effluent of the ozonated sand column indicating biological activity on the sand column (Figure 2). The geometric mean of the SPC in the GAC effluent of each disinfectant system increased dramatically to a level (10^3 counts per ml) similar to the nondisinfected influent water of the pilot column system.

Some positive total coliforms were observed (Table 2). Those detected in the disinfection systems influent and sand filter effluent are

suspected to be sample error. A majority of the positive samples observed in the GAC columns occurred at the start of the pilot plant.

Organic Surrogate By-Products

Two organic surrogates were evaluated for the disinfectant systems. These surrogates were total organic carbon (TOC) and total organic halide (TOX). The TOC concentrations for each disinfectant stream after 30 minutes of contact time were similar. Average values for these streams were 3.3 mg/L, 3.0 mg/L, 3.3 mg/L, 3.4 mg/L, and 3.3 mg/L, respectively, for nondisinfected, ozone, chlorine dioxide, chloramine, and chlorine. Although these concentrations have not been evaluated statistically, ozone appears to effect a slight TOC reduction (3.3 mg/L vs. 3.0 mg/L), possibly in part due to aeration.

When these disinfectant streams were passed through sand columns, only the ozone stream showed a TOC concentration reduction. The average TOC concentration in the effluent sand column was 2.5 mg/L while the concentrations for all the other disinfectant stream effluents were comparable to their influent values. The average reduction of TOC across the ozone stream sand column was 0.5 mg/L attributable to biological activity on the sand. This same phenomenon was observed for granular activated carbon (GAC) columns. At approximately 180 days "steady-state" conditions occurred whereby all disinfectant streams had a GAC effluent concentration of about 2.7 mg/L except for ozone which was approximately 2.2 mg/L.

The instantaneous TOX concentration for the non-disinfectant stream averaged 25 mg/L. This same water ozonated with 30 minutes contact

time produced an average concentration of 15 mg/L indicating that some oxidation occurred. Subsequent tests showed that aeration also contributed to this reduction. The instantaneous TOX average concentration for chlorine dioxide, chloramine, and chlorine after 30 minutes contact time was 85 ug/L, 117 ug/L, and 263 ug/L, respectively. Figure 3 illustrates the relative differences in TOX concentration after disinfection during the one year test period. Subtracting the nondisinfected stream from the disinfected streams showed an average instantaneous TOX by-product formation of 60, 92, and 238 ug/L, respectively. Conversely ozone disinfection did not produce any instantaneous by-products but actually reduced the concentration by 10 ug/L, possibly in part due to aeration.

The concentration of instantaneous TOX in the sand column effluent of each disinfection system was comparable to their respective influents. Average TOX concentrations were 23, 14, 83, 117, and 258 ug/L, respectively, for the nondisinfected, ozone, chlorine dioxide, chloramine, and chlorine effluents. The concentration of instantaneous TOX in the GAC effluents was influenced by the amount applied to the columns. The higher the influent concentration (Figure 3), the faster the breakthrough and the higher the effluent TOX concentrations.

Most treatment plants that use ozone or chlorine dioxide do so as a predisinfectant with addition normally to the raw water. In order to maintain a disinfectant residual in the distribution system, either chlorine or monochloramine is usually added after treatment. Samples from the pilot plant were stored for 5 days to simulate the end of a distribution system. These samples from each system were maintained with a chlorine

and/or monochloramine residual, however, the residuals were higher than would be expected in a water treatment system.

The 5-day terminal TOX concentrations produced from the chlorine residual samples were significantly higher than the instantaneous values. Figure 4 shows the average TOX concentrations for three levels of treatment. Ozone and chlorine dioxide pre-treatment reduced the available TOX precursor. The total 5-day concentration of TOX was reduced by use of GAC as compared to conventional sand filtration for all disinfection systems. Those samples stored with a monochloramine residual showed a slight increase in TOX concentration for some systems and a decrease in other systems.

Organic Profile

Flame ionization detection and electron capture chromatograms were used to provide an overall indication of the effect of using various disinfectants. As shown in Figure 5, chlorination appears to produce the most peaks in the low to medium molecular weight range followed by chloramination, chlorine dioxide, and ozone as compared to nondisinfected water. In the higher molecular weight range, two peaks do not appear after ozonation that are present in the other chromatograms. These general observations are discussed in the following sections.

Volatile Organics

Trihalomethanes

The trihalomethane (THM) species formed during the various disinfection processes were chloroform > bromodichloromethane > dibromochloromethane > bromoform. Chloroform accounted for about 75 percent of the THMs with very little dibromochloromethane and relatively no bromoform formed.

After 30 minutes of contact time average THM concentrations were 1.1 ug/L for the ozone system, 1.3 ug/L for the chlorine dioxide system, 4.5 ug/L for the chloramine system, and 34 ug/L for the chlorine system. The nondisinfected system had 1.3 ug/L of THM. The THM formed by chlorination was removed by GAC for about 60 days until breakthrough and for chloramine the removal was about 80 days until breakthrough.

Five-day average THM concentrations for sand filtration and GAC effluent streams that have been chlorinated are shown in Figure 6. Only after GAC has removed THM precursors is the concentration close to the promulgated standard of 100 mg/L. Subsequent disinfection of these same effluents with chloramine instead of chlorine produced lower average THM concentrations.

Other Volatile Organics

The concentrations of 1,2-dichloroethane (DCE) in the nondisinfected influent to the column system ranged from below detection limit (0.1 ug/L) to 7 ug/L. Thirty minutes of disinfectant contact time with ozone, chlorine dioxide, chloramines, and chlorine produced no significant change in DCE concentration. This was also the case for the sand column effluents of each disinfectant process stream. Effluent concentrations of the nondisinfected, ozone, chlorine dioxide, and chloramine GAC columns were similar. DCE concentrations for the chlorine GAC column was higher after breakthrough, possibly because of desorption.

Other volatile organics detected in the influent were dichloromethane, trichloroethylene, 1,1,2-trichloroethane, and carbon tetrachloride. These compounds occurred infrequently at concentrations

below 0.1 ug/L except for one occurrence where trichloroethylene was 20 ug/L. No increase in concentration of these organics was noted after disinfection.

Non-Volatile Organics

Chlorinated Hydrocarbons

The herbicide atrazine and the insecticide alachlor were present in the influent to the pilot system throughout the study. Influent atrazine concentrations ranged from 23-249 ng/L with an average of 80 ng/L. The influent atrazine concentration was not affected by chlorine dioxide, chloramine, and chlorine disinfection. However, ozonation produced an average removal of 83% relative to the nondisinfected influent. No concentration change was noted after sand filtration. GAC filtration removed the atrazine (95-97%) throughout the one-year operational period.

Alachlor levels in the nondisinfected influent of the pilot column system ranged from 13-593 ng/L with an average of 127 ng/L. As with atrazine, alachlor was also not affected by chlorine dioxide, chloramine, and chlorine disinfection but its concentration was reduced an average of 84% by ozonation. The sand column effluent was comparable to its influent. GAC removed 94-97% of the alachlor with no evidence of breakthrough during the study.

Other chlorinated hydrocarbon insecticides (CHI) were evaluated as a total sum of all the individual CHIs monitored during the study except atrazine and alachlor. Table 3 list the CHIs with their frequency of occurrence and the minimum, maximum, and average concentrations at which they were detected. The total CHI concentration in the

nondisinfected influent to the pilot column system ranged from 18-88 ng/L with an annual average of 36 ng/L. The concentration of these substances was unchanged after disinfection except for ozone which produced an average total CHI reduction of 57%. Sand filtration had no effect on the CHI concentration. GAC removed the CHI from 90-93% over the one-year operational period.

Total Alkylbenzene

The specific alkylbenzenes grouped to form the total alkylbenzenes evaluated during the study are shown in Table 4. The total alkylbenzene concentration in the nondisinfected influent ranged from 59-10,300 ng/L with an average of 590 ng/L. Thirty minutes of disinfectant contact time with chlorine dioxide, chloramine, and free chlorine produced an increase in the total alkylbenzene concentration of 11, 14 and 100%, respectively. Ozonation, however, reduced the total alkylbenzene concentration by 52%.

Sand filtration had some effect on the total aklylbenzene concentration. Removals of 49 and 37% were observed for the nondisinfected and chlorine systems although the chlorine concentration was still 20% greater than that of the nondisinfected influent. Loading of alkylbenzenes on the chlorine GAC columns was considerably greater than that of the other GAC columns. GAC removed on the average 73% of the alkylbenzenes of the chlorine stream (43% compared to the nondisinfected influent). No additional removal by GAC was noted for the ozone stream but 40-45% concentration reductions by GAC relative to the nondisinfectant influent were observed for the chlorine dioxide and chloramine systems.

Total Alkane

Total alkanes evaluated consisted of a summation of all the normal alkanes listed in Table 5. The total alkane concentration in the non-disinfected influent averaged 50 ng/L with a range of 10-150 ng/L. Ozonation reduced the concentration of the total alkanes by an average of 35%. Addition of the other disinfectants had no effect on the total alkane concentration. No reductions in the total alkane concentrations were observed through sand filtration. Similar concentration reductions occurred through GAC treatment for all of the streams (44-52%).

Total Phthalate

Total Phthalate is comprised of those phthalates listed in Table 6 that were monitored during the operational period. The total phthalate concentrations in the nondisinfected influent ranged from 70 to 470 ng/L with an average of 180 ng/L. Ozonation produced an average total phthalate reduction of 11%. No significant changes in total phthalate levels occurred for the other disinfectants. Average reductions of 20, 4, 10, 20, and 10% occurred through sand filtration for the nondisinfected, ozone, chlorine dioxide, chloramine, and chlorine systems, respectively. Average removals by GAC were 44-50% for each system.

Total Chlorobenzene and Nitrobenzene

Total chlorobenzene and total nitrobenzene consisted of those compounds listed in Table 7. Total chlorobenzene concentrations in the nondisinfected influent ranged from 4 to 304 ng/L with an average of 100 ng/L. Nitrobenzene concentrations ranged from a minimum of 0.1 ng/L for 2-nitrotoluene to 260 ng/L for 2,4-dinitrotoluene. Ozonation

produced an average 68% concentration reduction for total chlorobenzene and 61% for total nitrobenzene. Conversely, chlorination resulted in a 75% increase in total chlorobenzene and 43% increase in total nitrobenzene. An average total chlorobenzene reduction of 26% occurred through sand filtration for the chlorinated system but the effluent concentration was still 43% greater than the nondisinfected influent. No reduction was seen for the total nitrobenzene. The effluent concentrations from the GAC were comparable for all the disinfectant systems with removals ranging from 93-96% for the total chlorobenzene and 81-92% for total nitrobenzene.

Other Non-Volatile Organics

Two alkylaldehydes, octanal and nonanal, were quantified. When summed, these two constituents had a nondisinfected influent range from below detection to 37 ng/L with an average of 14.4 ng/L. An average uniform increase in the total alkyaldehyde of 144% was observed for ozonation while a relatively non-uniform increase of 56% occurred for the chlorine system relative to the nondisinfected influent. Average reductions of 62% and 26% were observed, respectively, across the sand columns of the ozone and chlorine streams relative to their respective influents. Essentially, no reductions were observed for GAC adsorption.

Other non-volatile organics monitored included tributylphosphate, triphenylmethane, 4 nonylphenol, and d-fenchone. Table 8 summarizes the effect of disinfection and treatment for these compounds.

Summary and Conclusions

An on-site pilot plant at Jefferson Parish, Louisiana was con-

structed to evaluate, during a one-year period, four different disinfectants (ozone, chlorine dioxide, chloramine, and chlorine) during parallel operation. Various organics, including surrogates such as TOC and TOX, were evaluated to investigate the effects of disinfection and treatment by sand and GAC filtration.

FID and EC profiles were run that generally showed that chlorination and chloramination produced more peaks in the low molecular weight range of the chromatogram than the other disinfectants when compared to nondisinfection. Conversely, ozonation produced fewer peaks when compared to nondisinfection for the entire molecular range evaluated. Ozonation reduced the TOC and instantaneous TOX average concentrations by 0.3 mg/L and 10 ug/L respectively. The average concentration of TOC for the other disinfectants was comparable to nondisinfection (3.3 mg/L). The average instantaneous TOX concentration for chlorine dioxide, chloramine and chlorine disinfection after 30 minutes contact time increased by 60, 92, and 238 ug/L, respectively, from a nondisinfected concentration of 25 ug/L.

The volatile organics most effected by disinfection (chlorination) were the trihalomethanes. After 30 minutes contact time average THM concentrations were 1.1 ug/L, 1.3 ug/L, 4.5 ug/L, and 34 ug/L, respectively, for the ozone, chlorine dioxide, chloramine, and chlorine systems. No significant change in concentration was noted after disinfection for other volatile organics evaluated such as 1,2-dichloroethane, dichloromethane, trichloroethylene, 1,1,2-trichloroethane, and carbon tetrachloride.

Nonvolatile organics evaluated consisted of atrazine, alachlor, other total chlorinated hydrocarbon insecticides, total alkylbenzenes, total alkanes, total phthalates, total chlorobenzenes, total nitrobenzenes, total alkylaldahydes, and others. Ozonation produced an average concentration reduction of 83%, 84%, 57%, 52%, 35%, 11%, 68%, and 61%, respectively, for atrazine, alachlor, total CHI, total alkylbenzenes, total alkanes, total phthalates, total chlorobenzenes, and total nitrobenzenes. Conversely, an average increase of 144% was observed for the total alkylaldehydes, octanal and nonanal, after ozonation with sand filtration reducing the concentration to essentially the nondisinfected level.

Chlorination produced no concentration change for atrazine, alachlor, total CHI, total alkanes and total phthalates. An increase in concentration was observed after chlorination for total alkylbenzenes, total chlorobenzenes, total nitrobenzenes, and total alkylaldahydes of 100%, 75%, 43%, and 56%, respectively. No significant concentration change was observed for atrazine, alachlor, total CHI, total alkanes, total phthalates, total chlorobenzenes, total nitrobenzenes and total alkylaldahydes after disinfection with chloramine and chlorine dioxide. A slight concentration change was noted for the other nonvolatiles.

Sand filtration had some effect on the total alkylbenzenes, total phthalates, total chlorobenzenes, and total alkylaldahydes with lower concentrations in the effluent as compared to the influent. GAC removed the volatile organics for a period of time (usually <100 days) before breakthrough. GAC effectively removed the chlorinated hydrocarbons,

total alkylbenzenes, total alkanes, total chlorobenzenes, total nitrobenzenes, and total alkylaldehydes for the one year operational period. The total phthlates were effectively removed for about 250 days before the ozonated stream broke through.

Of the disinfection streams evaluated, ozone appears to be the disinfectant of choice because less organic concentrations were detected during its use. However, there are still unanswered questions concerning what happens to the organics after ozonation. Are these organics oxidized and destroyed, are they converted to other organics that are more biodegradable, are they more water soluble and not extractable making them not detectable, etc.? Consequently more research is needed to fully understand the performance and cost aspects of disinfection.

Acknowledgements

The above work is part of a project entitled "Evaluation of Modular Full Scale Organic Treatment Removal Systems" sponsored by U.S.EPA--Cooperative Agreement CS806925.

The authors want to thank the following for their help in the research effort and in completing this paper: Jack DeMarco of the Cincinnati, Ohio Water Works and Noel V. Brodtmann of Environmental Professionals Limited, Metairie, Louisiana, for their initial involvement in starting the project, Keith Carswell and Jim Goodrich of the U.S.EPA for their technical review, and Sally Stoll for typing the manuscript.

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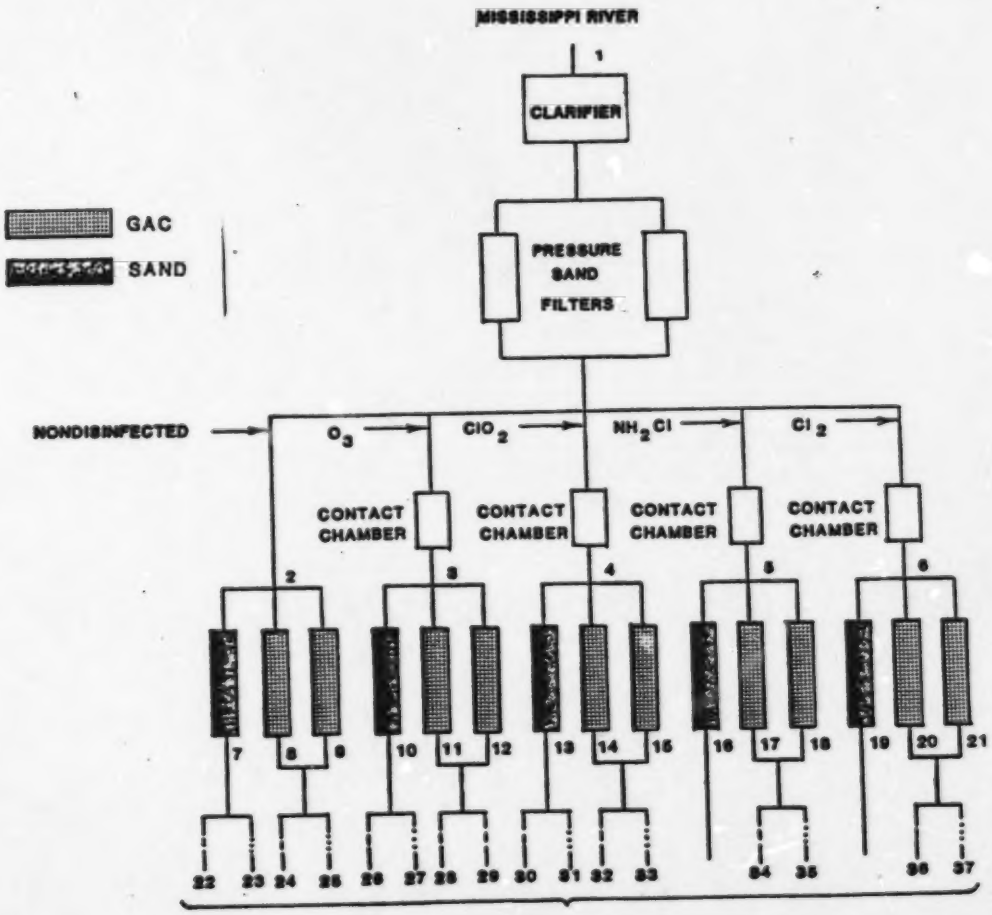


FIGURE 1. FLOW SCHEMATIC OF JEFFERSON PARISH, LA. PILOT PLANT

Table 1. Average Thirty Minute Disinfectant Residuals of Each Disinfectant Stream

PROCESS STREAM	DISINFECTANT CONSTITUENTS	AVERAGE RESIDUAL, mg/L
OZONE	OZONE	0.5 as O_3 (0.7 as Cl_2)
CHLORINE DIOXIDE	CHLORITE	0.6 as ClO_2^- (1.3 as Cl_2)
	CHLORINE DIOXIDE	0.5 as ClO_2 (1.3 as Cl_2)
	MONOCHLORAMINE	0.2 as NH_2Cl (0.1 as Cl_2)
	DICHLORAMINE	0.1 as $NHCl_2$ (0.1 as Cl_2)
	CHLORINE	0.1 as Cl_2
CHLORAMINE	MONOCHLORAMINE	2.1 as NH_2Cl (1.4 as Cl_2)
	DICHLORAMINE	0.4 as $NHCL_2$ (0.3 as Cl_2)
	CHLORINE	0.0 as Cl_2
CHLORINE	CHLORINE	1.0 as Cl_2
	DICHLORAMINE	0.3 as $NHCl_2$ (0.2 as Cl_2)
	MONOCHLORAMINE	0.2 as NH_2Cl (0.1 as Cl_2)

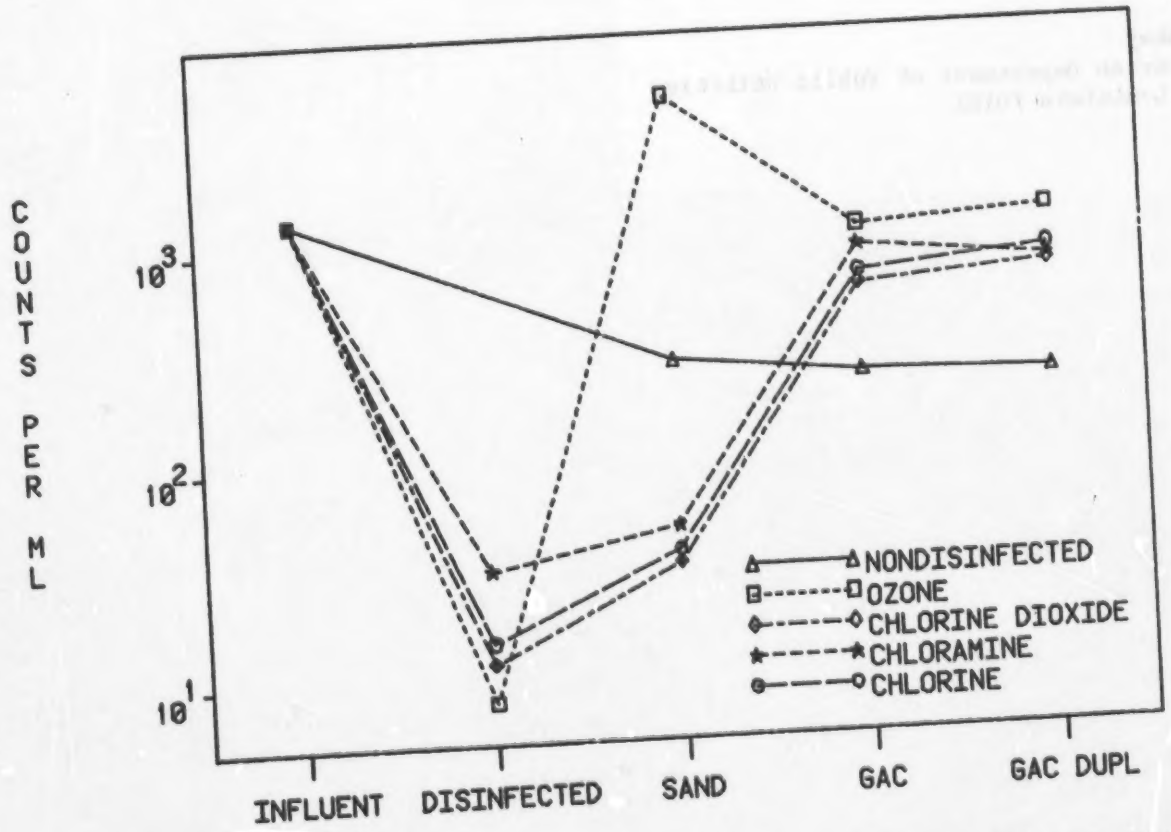


FIGURE 2. AVERAGE GEOMETRIC MEANS OF HETEROTROPHIC BACTERIA JEFFERSON PARISH, LA. PILOT PLANT

Table 2. Number of Positive Coliforms[a]
Jefferson Parish, LA. Pilot Plant

	NONDISIN-FECTED	OZONE	CHLORINE DIOXIDE	CHLORAMINE	CHLORINE
30 Minutes Contact	149[b]	0	2	1	1
Sand Effluent	91	1	2	0	1
GAC Effluent	125	3	3	7	8
GAC Duplicate Effluent	127	0	5	4	11

[a] 159 samples (3 samples per week for 53 weeks)

[b] no contact chamber and no disinfection

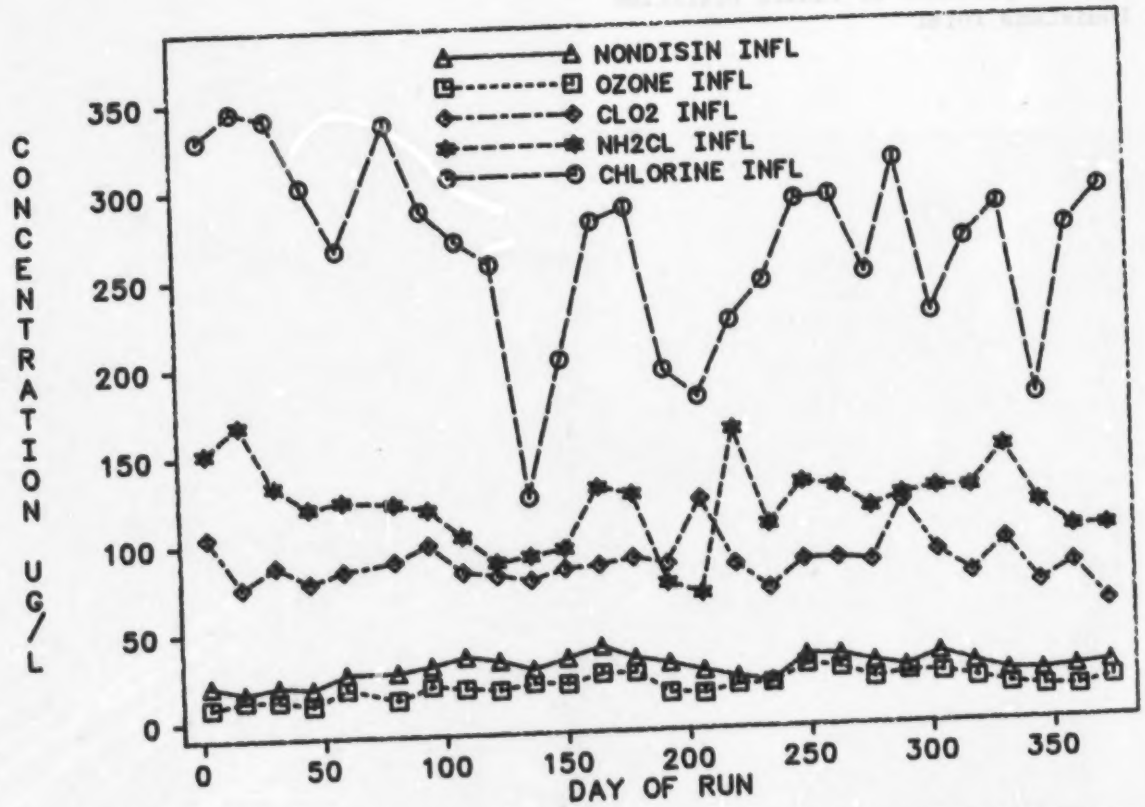


FIGURE 3. TOX CONCENTRATIONS AFTER 30 MINUTES CONTACT TIME
JEFFERSON PARISH, LA. RESEARCH PROJECT

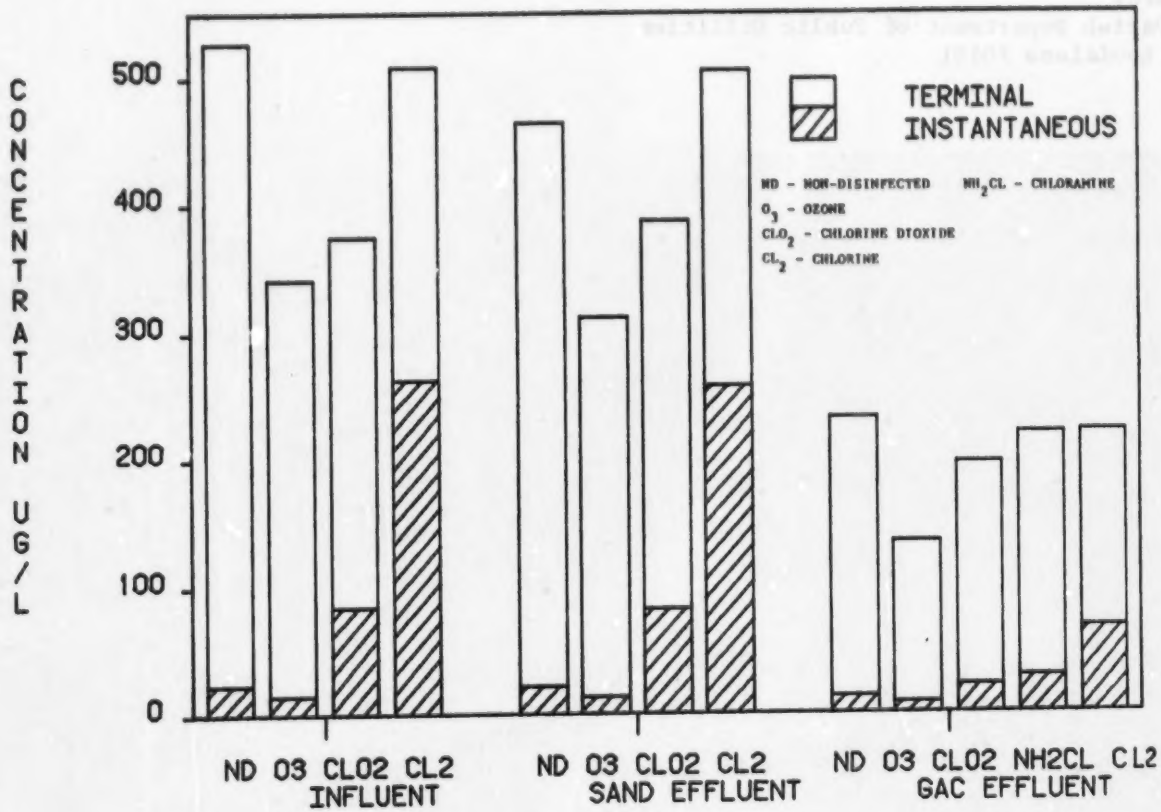
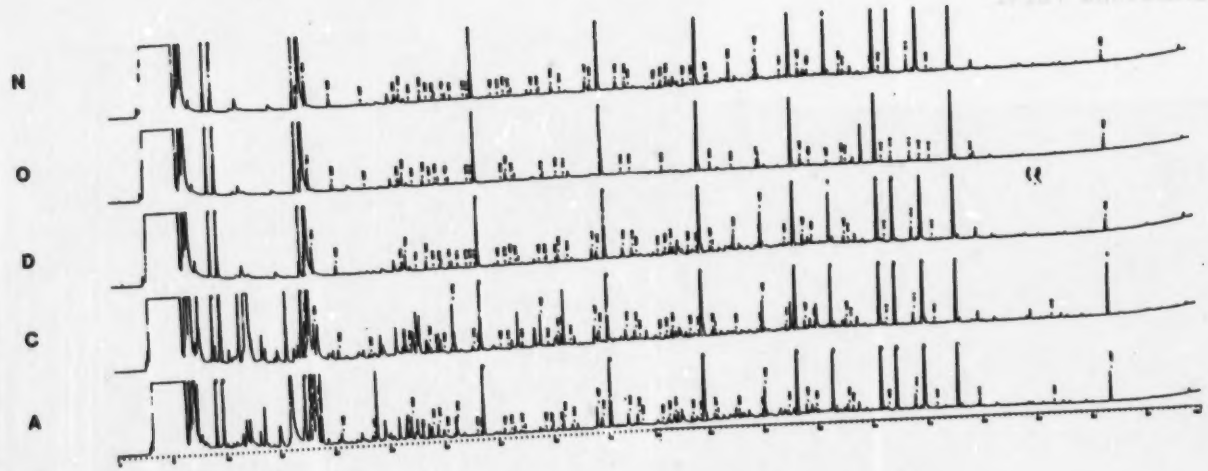


FIGURE 4. AVERAGE 5-DAY TERMINAL TOX (CL2 AT 28° C)
JEFFERSON PARISH, LA. PILOT PLANT



N - non-disinfected
O - ozone
D - chlorine dioxide
C - chlorine
A - chloramine

FIGURE 5. FID CHROMATOGRAMS
JEFFERSON PARISH, LA. RESEARCH PROJECT

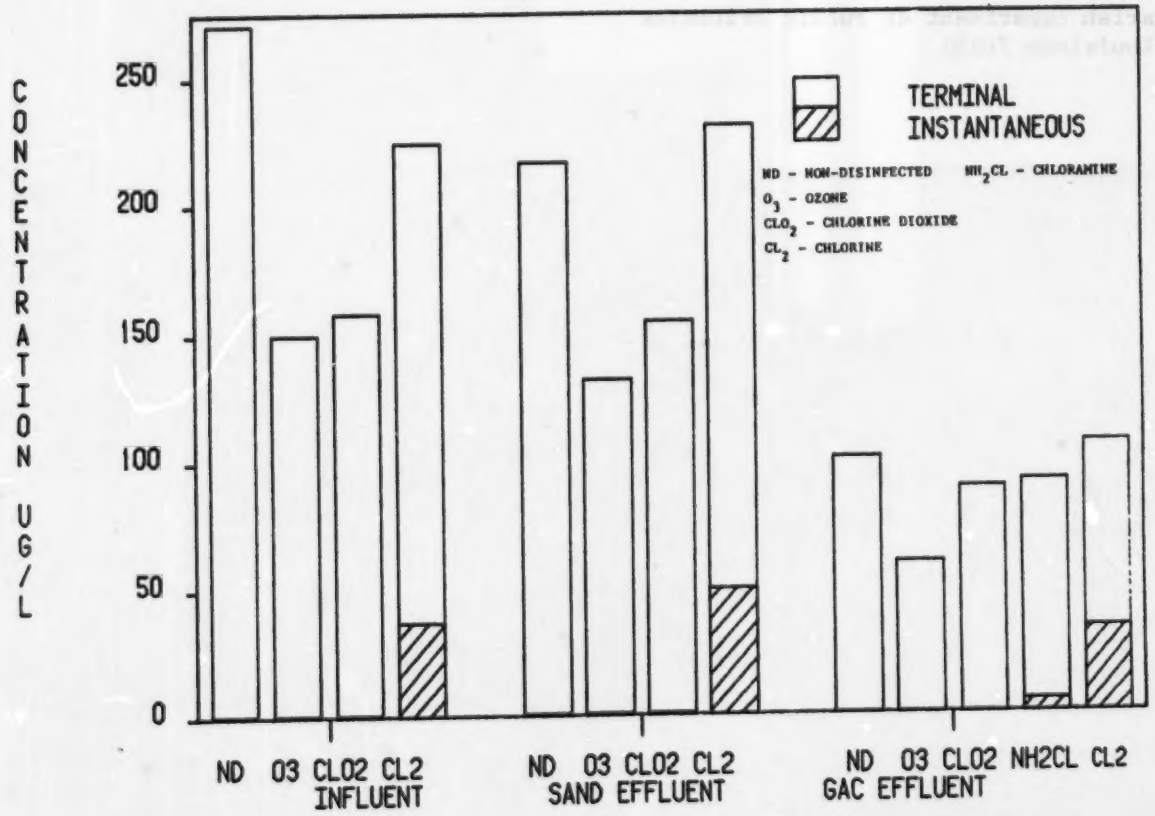


FIGURE 6. AVERAGE 5-DAY TERMINAL THM (CL2 AT 28°C)
JEFFERSON PARISH, LA. PILOT PLANT

Table 3. Concentration of Chlorinated Hydrocarbon Insecticides (CHI) in the Nondisinfected Influent

CHI	FREQUENCY %	CONCENTRATION (ng/L) MIN	MAX	AVE
aldrin	100	0.20	0.92	0.53
α-BHC	100	1.14	6.75	2.78
β-BHC	100	0.87	3.33	1.64
λ-BHC	100	0.40	9.06	1.39
α-chlordane	100	0.12	0.47	0.27
λ-chlordane	100	0.15	0.55	0.31
oxy-chlordane	92	0.02	0.35	0.09
α-chlordene	89	0.02	0.46	0.14
β-chlordene	93	0.08	32.5	7.55
λ-chlordene	96	0.06	0.77	0.43
DCPA[a]	100	0.17	5.42	1.42
o,p'-DDD	100	0.13	1.13	0.44
m,p'-DDD	56	0.03	1.34	0.36
p,p'-DDD	93	0.17	1.28	0.57
o,p'-DDE	96	0.08	0.83	0.30
p,p'-DDE	100	0.06	0.32	0.16
o,p'-DDT	59	0.03	7.80	0.68
p,p'-DDT	85	0.07	1.25	0.36
dieldrin	100	1.63	5.80	2.84
endosulfan-2	96	0.02	0.72	0.20
endrin	100	0.25	1.58	0.67
heptachlor	92	0.03	33.3	6.95
heptachlor epoxide	100	0.28	1.68	0.73
hexachlorobenzene	100	0.35	1.59	0.66
pentachloronitrobenzene	96	0.04	0.27	0.15
perthane	77	0.86	23.4	8.99

[a]dimethyl-2,3,5,6-tetrachloroterephthalate

Table 4. Concentration of Alkylbenzenes in the Nondisinfected Influent

ALKYLBENZENES	FREQUENCY %	CONCENTRATION (ng/L) MIN	MAX	AVE
cumene	72	0.75	959.	80.4
p-cymene	85	0.31	13.1	1.70
1,3-diethylbenzene	92	0.39	17.0	2.54
1,4-diethylbenzene	85	0.27	11.1	1.70
ethylbenzene	75	0.14	1985.	121.
2-ethyltoluene	100	0.60	21.5	4.08
3-ethyltoluene	89	1.29	51.0	9.96
4-ethyltoluene	85	0.64	112.	10.3
1,2,3,4-tetramethylbenzene	98	0.58	18.2	3.87
1,2,3,5-tetramethylbenzene	94	0.98	15.6	3.47
1,2,4,5-tetramethylbenzene	96	0.86	14.5	3.49
1,2,3-trimethylbenzene	100	1.89	32.5	6.73
1,2,4-trimethylbenzene	100	6.19	91.8	19.1
1,3,5-trimethylbenzene	100	1.90	43.1	8.24
o-xylene	98	5.77	1912.	120.
m-&p-xylene[a]	96	1.18	6514.	256.

[a]coeluting peaks

Table 5. Concentration of Normal Alkanes in the Nondisinfected Influent

NORMAL ALKANES	FREQUENCY %	CONCENTRATION (ng/L) MIN	MAX	AVE
decane	87	0.21	18.0	2.19
undecane	89	0.01	4.93	1.59
dodecane	96	0.24	14.3	3.23
pentadecane	94	0.29	17.5	5.34
hexadecane	92	1.29	15.5	5.73
heptadecane	98	5.21	31.1	11.1
nonadecane	96	1.11	8.03	3.21
eicosane	70	1.80	114.	33.6

Table 6. Concentration of Phthalates in the Nondisinfected Influent

PHTHALATE	FREQUENCY	CONCENTRATION (ng/L) MIN	MAX	AVE
diethylphthalate	96	28.1	98.6	53.7
dipropylphthalate	49	0.62	11.4	3.38
diisobutylphthalate	98	2.45	14.5	6.89
dibutylphthalate	98	17.5	362.	72.1
1,2-butylbenzylphthalate	92	2.38	32.0	10.1
bis-2-ethylhexylphthalate	77	0.59	29.7	4.54
dioctylphthalate	94	4.18	103.	34.0

Table 7. Concentration of Chlorobenzenes and Nitrobenzenes in the Nondisinfected Influent

CHLOROBENZENE	FREQUENCY %	CONCENTRATION (ng/L) MIN	MAX	AVE
1,2-dichlorobenzene	89	0.73	24.0	7.54
1,3-dichlorobenzene	64	0.05	8.00	1.89
1,4-dichlorobenzene	94	1.41	62.1	9.85
1,2,4-trichlorobenzene	72	0.61	20.2	6.20
1-chloro-2-nitrobenzene	91	5.91	80.5	26.2
1-chloro-4-nitrobenzene	91	0.48	214.	61.2
NITROBENZENE				
nitrobenzene	64	1.1	53	9.5
2-nitrotoluene	94	0.1	5.6	2.6
2,4-dinitrotoluene	89	0.9	260.	18.

Table 8. Data for Some Selected Non-Volative Organics

COMPOUND	CONCENTRATION, ng/L Min	Max	Ave	DISINFECTION O_3	CL_2	SAND O_3	SAND CL_2	GAC O_3	GAC CL_2
tributylphosphate	9.4	158.	40.7	89%R[a]	NE[b]	NE	NE	(96-98%)R	
tripenylmethane	0.83	21.4	3.3	38%R	26%R	53%	NE	(52-65%)R	
4-nonylphenol	5.2	207.	59.5	72%R	54%R	NE	NE	NE (74-82%)R	
d-fenchone	0.36	17.7	5.6	59%R	133%I[c]	NE	40%R	(80-94%)R	

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[a] R = removal

[b] NE = no effect

[c] I = increase

PRODUCTS IDENTIFIED AT AN ALTERNATIVE DISINFECTION PILOT PLANT
By Ben W. Lykins, Jr. and Wayne Koffskey

KEY WORDS

Drinking Water
Disinfection
Chlorine
Monochloramine
Chlorine Dioxide
Ozone
Disinfection By-Products